ALMA Memo 274
Reconfiguring the ALMA Array

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Abstract

The sensitivity losses which result from configuration changes are investigated. It is shown that it is preferable to move a small number of antennas (typically 4) and re-calibrate their positions and pointing constant every day during the configuration change, rather than to attempt moving a large (16 – 32) number before performing the calibration session.

This requires the ALMA to support a sub-array mode in which one sub-array can continue observations of a scientific program, while the other one is observing in continuum in the 3 mm or 2 mm band. Such a sub-array capability has design consequences in the local oscillator system for the antennas and the correlator.

If sub-arrays are not possible, the equivalent time loss due to a configuration change is about 31 hours for 2 transporters. In all cases, there is little gain in having more than 2 transporters.

1 Introduction

In previous ALMA memos, several suggestions have been made for configurations. I will broadly divide these configurations in two categories: 1) **continuous** configurations, which allow to change the longest baseline more or less continuously, and 2) **discrete** configurations, which have well separated baseline ranges. While continuous configurations obviously have some advantage in proposing any angular resolution within the available range, no analysis have been performed yet in term of reconfiguration time or scheduling policy.

This memo addresses the first issue (reconfiguration time) in some details, independently of any particular choice of configuration set.

2 Notations

The following table gives the notations:

Notation	Designation	Typical value
N	Total number of antennas	64
N_m	Number of antennas moved before re-calibration	
N_M	Maximum number of antennas moved in one day	(8)
N_d	Minimum number of days for a configuration change	(8)
N_x	Number of antennas required for re-calibration	4 to 8
N_t	Number of transporters	1 to 4
T_a	Time to move one antenna	2 hr
T_w	Available time per day for antenna motions	8 hr
T_b	Time required to calibrate baselines	1 hr
T_p	Time required to calibrate pointing	1 hr

The maximum number of antennas which can be moved in one day is obviously

$$N_M = \frac{T_w \times N_t}{T_a} \tag{1}$$

which is $N_M = 8$ with the default values in definition table. The corresponding minimum number of days to complete a configuration change (assuming all antennas have to be moved, for simplification) is

$$N_d = \frac{N}{N_M} = \frac{N \times T_a}{N_t \times T_w} \tag{2}$$

i.e. 8 days in the example above. The number of antennas used for recalibration N_x must be at least $N_m + 1$, since we want the baseline solution for the moved antennas to be tied up to the same coordinate system than the remaining antennas.

3 Continuous reconfiguration

A possible option to change from one configuration to another is to change N_m per day while continuing observing with the remaining number of antennas $N - N_m$ where N is the total number of antennas in the array. The moved antennas are re-usable for astronomy as soon as their basic parameters (baseline coordinates and pointing parameters) have been re-calibrated.

In such a scheme, the day when motions are performed can be divided in three periods:

1. $T_p + T_b$ hours required for recalibration of the antenna pointing constants and baseline parameters, all moved antennas being calibrated simultaneously. During that time, N_x antennas ($N_x > N_m$) are used for calibration, and only $N - N_x$ antennas are available for astronomy.
2. $(N_m/N_t) \times T_a$ hours required for antenna motion. Only $N - N_m$ antennas are available for astronomy.
3. $D - T_p - T_b - (N_m/N_t) \times T_a$ hours (where D = 24 hours) in which all N antennas are available for astronomy.

The sensitivity of the array in each of this period is given by

$$\sigma_1 = \frac{Cte}{\sqrt{(N - N_x)(N - N_x - 1)(T_p + T_b)}} \tag{3}$$

$$\sigma_2 = \frac{Cte}{\sqrt{(N - N_m)(N - N_m - 1)(N_m/N_t \times T_a)}} \tag{4}$$

$$\sigma_3 = \frac{Cte}{\sqrt{N(N-1)(D - N_m/N_t \times T_a - T_p - T_b)}} \tag{5}$$

which can be compared to the sensitivity of array in a complete day

$$\sigma_0 = \frac{Cte}{\sqrt{N(N-1)D}} \tag{6}$$

In a re-configuration day, the final sensitivity is given by

$$\frac{1}{\sigma^2} = \frac{1}{\sigma_1^2} + \frac{1}{\sigma_2^2} + \frac{1}{\sigma_3^2} \tag{7}$$

From these equations, we can derive the *effective time loss* due to reconfiguration, i.e. the additional time required to obtain the same sensitivity than with the full array

$$T_{loss} = N_d \times D \times (1 - (\frac{\sigma}{\sigma_0})^2) \tag{8}$$

N_m	N_x 3	4	5	6	7	8
1	15.8	19.6	23.4	27.0	30.7	34.2
2	**13.8**	**15.7**	**17.6**	**19.5**	21.3	23.1
3		17.6	18.9	20.1	**21.3**	**22.6**
4			20.5	21.4	22.3	23.2

Table 1: Time lost because of reconfiguration, as function of the number of moved antennas N_m and the number of antennas used for calibration N_x, for 1 transporter. For discrete configuration change, the time lost is 20.5 hours, and 47.6 hours if no observation is possible during calibration.

4 One step reconfiguration

Rather than proceeding by *continuous reconfiguration*, one can decide to move antennas from one configuration to another in the shortest possible number of days, N_d as given in Eq.1-2. The effective time loss can be computed from Eqs.4-5, but using $N_x = N_m + 1$, since we must re-calibrate all moved antennas with the same coordinate system than the others before re-using them for observations.

$$\sigma_1 = \frac{Cte}{\sqrt{(N - N_m - 1)(N - N_m - 2)(T_p + T_b)}} \tag{9}$$

$$\sigma_2 = \frac{Cte}{\sqrt{(N - N_m)(N - N_m - 1)(N_m/N_t \times T_a)}} \tag{10}$$

$$\sigma_3 = \frac{Cte}{\sqrt{N(N-1)(D - N_m/N_t \times T_a - T_p - T_b)}} \tag{11}$$

This however assumes that we are able to observe with $N - N_m - 1$ antennas while calibrating with the N_m moved antennas plus one fixed. If this is not possible, the above equations become:

$$\sigma_2 = \frac{Cte}{\sqrt{(N - N_m)(N - N_m - 1)(N_m/N_t \times T_a)}} \tag{12}$$

$$\sigma_3 = \frac{Cte}{\sqrt{N(N-1)(D - N_m/N_t \times T_a - T_p - T_b)}} \tag{13}$$

$$\frac{1}{\sigma^2} = \frac{1}{\sigma_2^2} + \frac{1}{\sigma_3^2} \tag{14}$$

since no astronomical observation occurs during calibration time.

Values for the time losses corresponding to the three cases, as function of the number of moved antennas N_d and antennas used for array calibration N_x are given in Table 1 to Table 4 for 1 to 4 transporters. Table 5 summarizes the time losses for discrete configuration changes as function of the number of transporters.

It is also interesting to compare the above numbers to what would happen if more transporters were available. For example, if 4 transporters are available, the time lost for discrete configuration change drops to 17.8 hours, or 22.1 hours if no observation during calibration.

It is interesting to note that the time loss is not a monotonic function of the number of available transporters, except when observations are not possible during calibration. Integer ratios of the number of antennas to the number of transporters are highly favorable in all cases.

N_m	N_x 3	4	5	6	7	8	9
1	15.8	19.6	23.4	27.0	30.7	34.2	37.7
2	**9.9**	**11.8**	13.7	15.5	17.3	19.1	20.8
3		13.5	14.8	14.0	17.3	18.5	19.7
4			**12.7**	**13.6**	**14.5**	**15.4**	**16.2**
5				16.5	17.2	17.9	18.6
6					16.5	17.1	17.7
7						21.4	21.9
8							19.3

Table 2: Time lost because of reconfiguration, as function of the number of moved antennas N_m and the number of antennas used for calibration N_x, for 2 transporters. For discrete configuration change, the time lost is 19.3 hours, and 31.1 hours if no observation is possible during calibration.

N_m	N_x 3	4	5	6	7	8	9
1	15.8	19.6	23.4	27.0	30.7	34.2	37.8
2	**9.9**	11.8	13.7	15.5	17.3	19.1	20.8
3		**9.4**	**10.7**	**12.0**	13.2	14.5	15.7
4			12.7	13.6	14.5	15.4	16.3
5				12.5	13.3	14.0	14.7
6					**12.5**	**13.1**	**13.7**
7						17.2	17.8
8							15.5

Table 3: Time lost because of reconfiguration, as function of the number of moved antennas N_m and the number of antennas used for calibration N_x, for 3 transporters. For discrete configuration change, the time lost is 22.0 hours, and 30.0 hours if no observation is possible during calibration.

5 Discussion

Table 5 shows that time losses are (as expected) significantly minimized if calibration of the newly moved antennas can proceed while observations continue with the other antennas. For 2 transporters, the effective time gain is about 12 hours for each global configuration change. This gain increases to 18 hours if the antennas are moved by groups of 4, with 6 antennas used for the calibration process. Hence, contrary to simple expectations, it is actually advantageous (from the sensitivity point of view) to proceed in small steps for the configuration change. This happens because the number of antennas tied up for calibration can then be kept small, although it should still be large enough to offer sufficient signal to noise for baseline and pointing calibration. Of course, in such a case, one is left in a hybrid configuration for a longer time (16 days in the above example). This is a disadvantage if the configurations are quite different, but may be used quite effectively in the "continuous" configuration scheme.

Such strategies are only possible if ALMA can be used with sub-arrays. Sub-arrays can be divided in 3 classes:

1. Sub-arrays observing at a common frequency, but with different targets.
2. Sub-arrays observing different targets, and different frequencies, one of which is spectral line, the other continuum.
3. Sub-arrays observing different targets, and different spectral line frequencies.

N_m	N_x 3	4	5	6	7	8	9
1	15.8	19.6	23.4	27.0	30.7	34.2	37.8
2	**9.9**	11.8	13.7	15.5	17.3	19.1	20.8
3		**9.4**	10.7	12.0	13.2	14.5	15.7
4			**8.8**	**9.7**	**10.6**	**11.5**	12.3
5				12.5	13.3	14.0	14.7
6					12.5	13.1	13.7
7						13.1	13.6
8							**11.8**

Table 4: Time lost because of reconfiguration, as function of the number of moved antennas N_m and the number of antennas used for calibration N_x, for 4 transporters. For discrete configuration change, the time lost is 17.8 hours, and 22.1 hours if no observation is possible during calibration.

	N_t 1	2	3	4	5–7	8
(a)	20.5	19.3	22.0	17.8	22.5 – 22.7	15.1
(b)	47.7	31.1	30.0	22.0	26.2 – 24.6	16.0

Table 5: Time lost because of reconfiguration, as function of the number of available transporters, when observations are possible during calibration (a), or not (b).

In the first case, a single frequency reference can be provided to all antennas. In the second case, it may be possible (depending on the local oscillator system design) to derive the continuum frequency from the same frequency reference as used to synthesize the spectral line frequency. The last case will in general require two completely independent frequency references (although in some designs with very wideband receivers, it may be possible to provide the appropriate observing frequencies by using the correlator synthesizers). Note also that in all cases, in is desirable that the sub-arrays could operate independently from the acquisition point of view, i.e. that no synchronization between the sub-arrays be imposed by the system. One should be able to perform total power measurement (e.g. atmospheric calibration) with one sub-array while the other is in cross-correlation mode.

Case 2) is required for calibration during reconfiguration, because the exact observing frequency is not specified: it is sufficient for pointing and baseline calibration to observe in the 3 mm or 2 mm bands.

Besides the number of transporters, three parameters will influence the time loss: the time required to move one antenna, T_a, the time for baseline calibration T_b and the time for pointing calibration T_p. Based on the experience with the IRAM Plateau de Bure interferometer, $T_a = 2$ hr sounds a reasonable mean value. This includes the time for the transporter to go to the initial station, to pick up the antenna, move to the new station, and put the antenna into position. From IRAM experience again, $T_b + T_p = 2$ hr is a reasonable guess. It assumes that the first order pointing can be quickly recovered by using inclinometers. It is conceivable that this calibration time be slightly reduced, since pointing and baseline measurements can actually be done simultaneously, and since the ALMA antenna will have shorter slew time than the IRAM 15-m dishes. However, it is still necessary to sample the atmosphere for a significant time to provide accurate baseline measurements.